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THE CHARACTERIZATION OF BENTONITE SAMPLES BEN-1, -2 AND -3

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THE CHARACTERIZATION OF BENTONITE SAMPLES BEN-1, -2 AND -3

by

H.F. Steger and W.S. Bowman

SYNOPSIS

Three samples of "Wyoming" bentonite were prepared and characterized for use as compositional reference materials. BEN-1, -2 and -3 were each screened at 104 μm (-100 mesh) and blended.

Eleven laboratories provided results for Plate water absorption and Enslin water absorption by prescribed methods and for one or more of -200 mesh structure, +325 structure, m ure, Al_2O_3, CaO, CO_2, total Fe, Fe(II), K_2O, Na_2O, MgO, SiO_2, S and loss on ignition by methods of their choice. A full statistical analysis was performed only for Plate water for which recommended, i.e., consensus, values were assigned. Only overall mean values were calculated for the other characteristics; these can be described at best as information values.

SYNOPSIS

Trois échantillons de Bentonite du Wyoming ont été préparés et caractérisés afin de les utiliser comme matériaux de référence de composition. Les BEN-1, -2 et -3 ont été tamisés à une granulométrie de moins 104 µm et mélangées en lot d'argile.

Onze laboratoires ont soumis des résultats pour l'eau d'absorption "Plate" et l'eau d'asorption "Enslin" par des méthodes prescrites et pour un ou plus de la structure à 74 µm, la structure à 44 µm, l'eau adsorbée, Al_2O_3, CaO, CO_2, Fe total, Fe(II), K_2O, Na_2O MgO, SiO_2, S et la perte au chauffage par des méthodes de leur choix. Une analyse statistique complete ne fut accomplie que pour l'eau d'absorption "Plate" dont des valeurs recommandées (de consensus) ont été assignées. Rien que les valeurs moyennes ont été calculées pour les autres caractéristiques; Celles-ci peuvent être déscrites seulement comme des valeurs de renseignements.

INTRODUCTION

The main objective of the Canadian Certified Reference Materials Project (CCRMP) is to provide compositional reference ores, concentrates and related products typical of Canadian deposits and generally unavailable from other sources for use in analytical laboratories associated with mining, metallurgy and the earth sciences. The reference materials available from CCRMP are described in a catalogue available from CANMET, Energy, Mines and Resources Canada, Ottawa (1).

In August 1983, CCRMP agreed to a request from the Iron Ore Company of Canada to prepare a series of three bentonite samples for characterization by an interlaboratory program comprised of bentonite producers and users. R.D. Frans (Hanna Mining Company) chairman of a subcommittee of ASTM Committee E16 concerned with bentonite, undertook the organization of the interlaboratory program. The parameters of concern were:

1. Plate water absorption value by ASTM Method E946-83
2. Enslin water absorption value
3. Dry structure at 74 μm (-200 mesh)
4. Grit; wet structure at 44 μm (+325 mesh)
5. Moisture content
6. Content of SiO_2 Na_2O
   Al_2O_3 K_2O
   Fe_2O_3 S
   CaO CO_2
   MgO LOI

This report describes the results of the interlaboratory program and the statistical analysis of these results performed by CCRMP.

NATURE AND PREPARATION

The bentonite samples were donated to CCRMP by:

BEN-1, Wyo-Ben Inc.

BEN-2, Federal Bentonite

BEN-3, Black Hills Bentonite Co.

and are all examples of "Wyoming" bentonite (2). Extensive volcanic activity in western Wyoming and Idaho during the Cretaceous Period spewed vast quantities of ash into the atmosphere. Prevailing westerly winds blew this material eastward over Wyoming and South Dakota where it fell into the shallow seas that covered the area. Alteration of this ash produced bentonite. "Wyoming" bentonite in general contains 3 to 5 per cent grit, or non-bentonite material, part of which is unaltered volcanic debris; it is a sodium montmorillonite type, therefore high-swelling. Processing for the most part consists of drying and milling.

Each of the three bentonite samples was screened to pass 104 μm (-100 mesh) and tumbled in a 570-L blender for 15 h. In removing each sample from the blender, forty five 200-g subsamples were taken at regular intervals; the remainder of the material is stored in bulk. Approximately 172, 163 and 41 kg of BEN-1, BEN-2 and BEN-3, respectively, are available.

INTERLABORATORY PROGRAM

The laboratories participating in the interlaboratory program for BEN-1, BEN-2 and BEN-3 are listed alphabetically below:

Black Hills Bentonite Company
Mills, Wyoming
N.H. Ilgner

Canada Centre for Mineral and Energy Technology
Ottawa, Ontario
(2 independent analysts)
J.M.D. Wilson

(The) Cleveland-Cliffs Iron Company
Ishpeming, Michigan
K.G. Oja

Federal Bentonite
Belle Fourche, South Dakota
D. Hentz

(The) Hanna Mining Company
Nashwauk, Minnesota
R.D. Frans

Iron Ore Company of Canada
Sept-Iles, Quebec
L. Beaumont

Luossavaara-Kurunmavaara AB,
Malmberget, Sweden
L. Norlund

Sidbec-Normines Inc.
Port-Cartier, Quebec
G. Ouellet

Silver and Baryte Ores Mining Company
Athens, Greece
E. Voulgaris

Wyo-Ben, Inc.
Billings, Montana
D.J. Doan

Each laboratory was assigned a code number which bears no relation to its alphabetical order.

The interlaboratory program was of a semi-informal nature. Participating laboratories were requested to perform the Plate water absorption test on 10 replicate subsamples for as many different ceramic plates as possible, and to perform 10 replicate determinations of the Enslin water absorption value. Copies of ASTM Method E946-83 for water absorption and the method for Enslin water absorption value by H. Seger and E. Cramer (Chemisches Laboratorium fur Tonindustrie) were provided. Methods and replication for dry structure, grit, moisture content and chemical analysis were left to the discretion of individual laboratories. Without exception, single results and no methodological information was provided to CCRMP for these latter. The overall mean values of the parameters of interest in the bentonite samples are reported in Tables 1 to 3. Physical property and analytical information are summarized in Tables 4-6.

STATISTICAL TREATMENT OF RESULTS

ESTIMATION OF CONSENSUS VALUE AND 95% CONFIDENCE LIMITS

A) Plate Water Absorption

Sets of results whose means differed by more than twice the overall standard deviation from the initially calculated mean value were not used in subsequent computations to avoid biasing of the statistics. All results that were rejected are identified in Table 4.

A one-way analysis of variance technique was used to estimate the consensus value and its variance. This approach considers the results of the described interlaboratory program to be only one sampling out of a universal set of results. The data were assumed to fit the model (3).

$$x_{ij} = \mu + y_i + e_{ij}$$

where x_{ij} = the jth result in set i,

μ = the true consensus value,

y_i = the discrepancy between the mean of the results in set i ($\bar{x}_i.$) and μ, and

e_{ij} = the discrepancy between x_{ij} and $\bar{x}_i.$

It is assumed that both y_i and e_{ij} are normally distributed with means of zero and variance of ω^2 and σ^2, respectively. The significance of ω^2 is detected by comparing the ratio of between-set mean squares with within-set mean squares with the F statistic at the 95% confidence level and with the appropriate degrees of freedom.

The consensus value of the assumed model is estimated by the overall mean $\bar{x}..$:

$$\bar{x}.. = \sum_{i}^{k} \sum_{j}^{n_i} x_{ij} \Big/ \sum_{i}^{k} n_i$$

where n_i = the number of results in set i and

k = the number of sets.

The value of σ^2 is estimated by s_1^2 which is given by:

$$s_1^2 = \sum_{i}^{k} \sum_{j}^{n_i} (x_{ij} - \bar{x}_i.)^2 \Big/ \sum_{i}^{k} (n_i - k)$$

The value of ω^2 is estimated by:

$$\omega^2 = (s_2^2 - s_1^2) \Big/ \frac{1}{(k-1)} \left[\sum_{i}^{k} n_i - \sum_{i}^{k} n_i^2 / \sum_{i}^{k} n_i \right]$$

where

$$s_2^2 = \sum_{i}^{k} n_i (\bar{x}_i. - \bar{x}\ ..)^2 \Big/ (k - 1)$$

The variance of the overall mean is given by:

$$v[\bar{x}..] = \left[\sum_{i}^{k} n_i^2 / (\sum_{i}^{k} n_i)^2 \right] \omega^2 + \left[1 / \sum_{i}^{k} n_i \right] \sigma^2$$

and the 95% confidence limits for $\bar{x}..$ are

$$\bar{x}.. \pm t_{0,95\,(k-1)}\sqrt{V[\bar{x}..]}$$

It should be noted that 95% confidence limits denote that if the program was performed 100 times, it would be expected that the overall mean in 95 would fall within the prescribed limits.

In the above statistical treatment, where a laboratory determined Plate water absorption using more than one plate, each set of results was considered to be independent, i.e., each such set was elevated to laboratory status. For this reason, the average within-set standard deviation, σ_A, is a measure of the average repeatability of Plate water absorption per plate per laboratory.

B) Enslin Water Absorption Value

The mean of the Enslin value absorption determined by two laboratories for a four, eight and 24 h time period were calculated. Between-sets and within-set standard deviations were calculated.

C) Others

Outliers were identified (Table 6) by a subjective assessment of the physical significance of their difference from the other results and were excluded in the calculation of the mean, $\bar{x}..$, by:

$$\bar{x}.. = \sum_{i}^{k} x_i/k$$

and the between-laboratories standard deviation, ω, by:

$$\omega = \sqrt{\sum_{i}^{k} (x_i - \bar{x}..)^2/k-1}$$

DISCUSSION

PLATE WATER ABSORPTION

The between-laboratories, between-sets and within-set consensus is sufficiently good that the overall mean values for Plate water absorption may be given recommended status. The histograms for BEN-1, -2 and -3 are shown in Figure 1 and illustrate the degree of consensus.

OTHERS

The number of results available for the other properties and constituents are too few to present values calculated with a degree of certainty other than for information only. The scatter in the analytical data for the elements and oxides, particularly for Al_2O_3 and SiO_2, indicates clearly that appreciably more work would have to be done before these bentonites could serve as compositional reference materials. The authors must state however that they have no experience in the analysis of bentonites and accept the possibility that these samples may indeed be good enough for this purpose. They suggest that should additional characterization be undertaken in future, such effort should be limited to one sample and follow a more rigidly organized interlaboratory analysis program.

REFERENCES

1. Steger, H.F. "Certified reference materials"; CANMET Report 83-3E. CANMET, Energy, Mines and Resources Canada; 1983.
2. Thorson, T.A. "Wyoming bentonite"; Wyom Geol Assn Guidebook, 20th Field Conf, 195-195; 1968.
3. Brownlee, K.A. Statistical Theory and Methodology in Science and Engineering; New York: John Wiley and Sons, Inc.; 1960.

Table 1 - Recommended values and statistical parameters for Plate water absorption

Bentonite	No. of laboratories	No. of sets of results	No. of results	Overall mean	95% CL		σ_A*
					Low	High	
				Water absorption, wt %			
BEN-1	10	17	123	861	836	886	14
BEN-2	10	17	123	1026	997	1056	13
BEN-3	8	14	116	750	728	772	9

* Pooled within-set standard deviation

Table 2 - Overall mean values and statistical parameters for Enslin water absorption

Bentonite	Test period (h)	No. of laboratories	No. of sets of results	No. of results	Overall mean	ω*	σ_A
					Water absorption, wt %		
BEN-1	4	2	6	30	868	45	27
	8	2	3	20	897	72	10
	24	2	5	26	1071	32	41
BEN-2	4	2	6	30	1006	17	30
	8	2	3	19	1033	72	8
	24	2	6	30	1195	45	32
BEN-3	4	2	6	30	716	25	23
	8	2	3	20	739	45	11
	24	2	6	30	901	51	33

* Between-sets standard deviation

Table 3 - Mean value of other characteristics

Characteristic	No. of results	Mean ± standard deviation (mass %)		
		BEN-1	BEN-2	BEN-3
Structure, -200 mesh	7	90.5 ± 1.4	91.7 ± 1.1	87.8 ± 1.5
Structure, +325 mesh	6	5.5 ± 0.45	2.72 ± 0.24	5.5 ± 0.9
Moisture	6	4.94 ± 0.41	7.68 ± 0.36	7.01 ± 0.44
Al_2O_3	7	17.7 ± 1.2	19.49 ± 0.69	16.53 ± 0.72
CaO	6	1.47 ± 0.09	1.19 ± 0.08	1.67 ± 0.33
CO_2	4	1.06 ± 0.24	1.01 ± 0.20	1.39 ± 0.25
Fe, total	6	2.60 ± 0.13*	2.85 ± 0.23	3.13 ± 0.32
Fe(II)	2	0.19 ± 0.16	0.38 ± 0.11	0.63 ± 0.29
K_2O	6	0.63 ± 0.13	0.56 ± 0.09	0.48 ± 0.10
Na_2O	6	2.93 ± 0.15	2.29 ± 0.18**	2.53 ± 0.15
MgO	7	2.09 ± 0.14	2.40 ± 0.14	1.56 ± 0.10
S	4	0.15 ± 0.03	0.18 ± 0.03	0.15 ± 0.04
SiO_2	6	63.1 ± 1.8	60.4 ± 2.3	63.0 ± 2.2
LOI	7	6.7 ± 2.0	7.2 ± 1.9	6.5 ± 1.7

* 4 results only
**7 results

Table 4a - Reference Material BEN-1

	PLATE WATER ABSORPTION, WT %					MEAN	S.D.
LAB- 1	801.	814.	829.	805.	821.	816.80	11.40
	828.	829.	824.	800.	817.		
LAB- 1	797.	800.	815.	815.	817.	812.00	9.03
	823.	820.	820.	809.	804.		
LAB- 1	837.	823.	823.			827.66	8.08
LAB- 1	804.	810.	819.			811.00	7.54
LAB- 2	876.	877.	885.	889.	863.	873.30	15.32
	879.	893.	864.	841.	866.		
LAB- 2	855.	850.	853.	856.	842.	843.00	15.75
	822.	819.	855.	856.	822.		
LAB- 3*	997.	1010.	1040.			1015.66	22.05
LAB- 3	912.	942.	945.			933.00	18.24
LAB- 3	982.	960.	958.			966.66	13.31
LAB- 4	915.2	849.8	931.5	868.8	876.7	882.68	24.19
	867.8	874.8	876.8	892.7	872.7		
LAB- 5	871.	883.	891.	888.	907.	892.40	15.84
	916.	903.	908.	869.	888.		
LAB- 6	788.	794.	784.	783.	792.	784.50	7.27
	780.	791.	778.	785.	770.		
LAB- 7	892.	866.				879.00	18.38
LAB- 8	895.	874.	879.	896.	882.	885.20	9.83
LAB- 8	913.	922.	910.	925.	913.	916.60	6.50
LAB- 9	906.	903.	909.	928.	896.	903.20	19.36
	873.	891.	907.	937.	882.		
LAB- 9	1091.**	886.	930.	893.	896.	907.80	67.48
	876.	861.	860.	901.	884.		
LAB-10	844.	848.	860.	828.	843.	849.70	12.94
	833.	861.	869.	857.	854.		

* Outlying set of results
**Outlying value

Table 4b - Reference Material BEN-2

	PLATE WATER ABSORPTION, WT %					MEAN	S.D.
LAB- 1	972.	981.	980.	1000.	993.	986.30	10.81
	991.	997.	998.	980.	971.		
LAB- 1	957.	959.	945.	987.	993.	976.30	17.75
	985.	988.	1000.	977.	972.		
LAB- 1	995.	985.	986.			988.66	5.50
LAB- 1	997.	990.	983.			990.00	7.00
LAB- 2	1055.	1055.	1037.	1058.	1057.	1044.00	15.21
	1059.	1015.	1027.	1036.	1041.		
LAB- 2	1037.	1045.	1016.	1023.	1032.	1029.40	8.78
	1037.	1023.	1022.	1027.	1032.		
LAB- 3*	1132.	1148.	1150.			1143.33	9.86
LAB- 3	1126.	1110.	1122.			1119.33	8.32
LAB- 3	1136.	1110.	1102.			1116.00	17.77
LAB- 4	1062.0	1000.0	1021.0	1024.8	1021.8	1020.99	21.17
	1009.8	1046.9	1027.3	1001.3	995.0		
LAB- 5	1045.	1054.	1054.	1061.	1049.	1054.60	9.64
	1037.	1070.	1064.	1060.	1052.		
LAB- 6	923.	915.	931.	913.	921.	921.60	5.75
	919.	926.	928.	917.	923.		
LAB- 7	1024.	1059.				1041.50	24.74
LAB- 8	1100.	1091.	1106.	1099.	1097.	1098.60	5.41
LAB- 8	1098.	1105.	1098.	1091.	1092.	1096.80	5.63
LAB- 9	1088.	1107.	1062.	1104.	1075.	1081.00	17.75
	1072.	1096.	1064.	1085.	1057.		
LAB- 9	1056.	1051.	1043.	1047.	1052.	1046.20	20.18
	1028.	1010.	1029.	1081.	1065.		
LAB-10	1008.	1013.	1019.	965.	984.	1005.30	37.57
	987.	987.	987.	1001.	1102.**		

* Outlying set of results
**Outlying value

Table 4c - REFERENCE MATERIAL BEN-3

	PLATE WATER ABSORPTION, WT %					MEAN	S.D.
LAB- 1	720.	723.	697.	715.	707.	709.60	10.11
	714.	718.	709.	698.	695.		
LAB- 1	710.	713.	709.	705.	702.	704.70	4.71
	704.	702.	703.	702.	697.		
LAB- 1	734.	729.	733.			732.00	2.64
LAB- 1	727.	734.	725.			728.66	4.72
LAB- 2	749.	746.	756.	760.	745.	753.80	6.07
	760.	759.	758.	748.	757.		
LAB- 2	718.	726.	715.	751.	709.	729.00	18.85
	712.	719.	763.	727.	750.		
LAB- 3*	849.	855.	866.			856.66	8.62
LAB- 3*	847.	849.	846.			847.33	1.52
LAB- 3*	853.	846.	849.			849.33	3.51
LAB- 4	772.5	810.5	775.3	776.3	790.8	787.05	14.22
	794.3	775.3	801.0	773.0	801.5		
LAB- 5	796.	787.	797.	785.	779.	780.40	14.48
	780.	786.	783.	759.	752.		
LAB- 6	707.	715.	696.	721.	704.	708.40	8.52
	699.	717.	717.	703.	705.		
LAB- 7	767.					767.00	
LAB- 8	746.	749.	752.	753.	747.	749.40	3.04
LAB- 8	805.	811.	805.	801.	801.	804.60	4.09
LAB- 9	825.	809.	818.	815.	806.	806.60	13.16
	782.	814.	808.	800.	789.		
LAB- 9	772.	765.	759.	758.	767.	769.20	18.01
	759.	751.	760.	810.	791.		
LAB-10	742.	724.	728.	729.	725.	734.70	7.71
	741.	745.	734.	738.	741.		

*Outlying set of results

Table 5a - REFERENCE MATERIAL BEN-1

	ENSLIN VALUE (4 H), WT %					MEAN	S.D.
LAB- 1	800.	870.	830.	880.		845.00	36.96
LAB- 1	815.	825.	810.	785.		808.75	17.01
LAB- 1	885.	940.	930.	910.		916.25	24.28
LAB- 1	840.	880.	850.	820.		847.50	25.00
LAB- 1	785.	855.	825.	830.		823.75	28.97
LAB- 2	850.	938.	920.	895.	910.	908.50	27.50
	920.	910.	892.	950.	900.		

	ENSLIN VALUE (8 H), WT %					MEAN	S.D.
LAB- 8	955.	960.	972.	987.	962.	967.20	12.67
LAB- 8	945.	939.	935.	929.	945.	938.60	6.84
LAB-10	851.	851.	856.	835.	830.	840.90	10.06
	830.	835.	851.	835.	835.		

	ENSLIN VALUE (24 H), WT %					MEAN	S.D.
LAB- 1*	1240.	1300.	1255.	1300.		1273.75	30.92
LAB- 1	1085.	1115.	1105.	1050.		1088.75	28.68
LAB- 1	1155.	1175.	1150.	1045.		1131.25	58.50
LAB- 1	1140.	1070.	1055.	1000.		1066.25	57.64
LAB- 1	1085.	1105.	1100.	1015.		1076.25	41.70
LAB- 2	990.	1055.	1040.	1045.	1035.	1039.00	20.38
	1045.	1035.	1040.	1070.	1035.		

*Outlying set of results

Table 5b - REFERENCE MATERIAL BEN-2

	ENSLIN VALUE (4 H), WT %					MEAN	S.D.
LAB- 1	1000.	1050.	1020.	995.		1016.25	24.95
LAB- 1	915.	1005.	1005.	960.		971.25	43.08
LAB- 1	1010.	1055.	1060.	1030.		1038.75	23.22
LAB- 1	955.	1015.	995.	1000.		991.25	25.61
LAB- 1	1040.	985.	1065.	995.		1021.25	37.72
LAB- 2	988.	1020.	1005.	1022.	1050.	1003.00	26.00
	1000.	985.	980.	960.	1020.		

	ENSLIN VALUE (8 H), WT %					MEAN	S.D.
LAB- 8	1100.	1100.	1097.	1107.	1107.	1102.20	4.54
LAB- 8	1085.	1135.**	1076.	1070.	1083.	1089.80	25.95
LAB-10	978.	957.	989.	995.	962.	980.10	13.51
	995.	989.	968.	984.	984.		

**Outlying value

	ENSLIN VALUE (24 H), WT %					MEAN	S.D.
LAB- 1	1210.	1240.	1200.	1170.		1205.00	28.86
LAB- 1	1180.	1200.	1170.	1235.		1196.25	28.68
LAB- 1	1285.	1240.	1135.	1175.		1208.75	66.75
LAB- 1	1225.	1225.	1195.	1185.		1207.50	20.61
LAB- 1	1280.	1240.	1315.	1285.		1280.00	30.82
LAB- 2	1132.	1185.	1140.	1170.	1140.	1147.20	20.40
	1130.	1130.	1155.	1125.	1165.		

Table 5c - REFERENCE MATERIAL BEN-3

	ENSLIN VALUE (4 H), WT %					MEAN	S.D.
LAB- 1	645.	700.	690.	690.		681.25	24.62
LAB- 1	665.	715.	690.	700.		692.50	21.01
LAB- 1	700.	760.	750.	710.		730.00	29.43
LAB- 1	685.	690.	715.	712.		700.50	15.19
LAB- 1	745.	695.	690.	690.		705.00	26.77
LAB- 2	725.	765.	760.	760.	735.	744.00	17.91
	740.	770.	735.	725.	725.		

	ENSLIN VALUE (8 H), WT %					MEAN	S.D.
LAB- 8	730.	735.	747.	747.	735.	738.80	7.75
LAB- 8	780.	813.	803.	803.	791.	798.00	12.72
LAB-10	704.	699.	731.	726.	704.	709.60	12.58
	720.	704.	699.	694.	715.		

	ENSLIN VALUE (24 H), WT %					MEAN	S.D.
LAB- 1	945.	1160.	990.	950.		1011.25	101.19
LAB- 1	815.	860.	840.	850.		841.25	19.31
LAB- 1	835.	885.	885.	880.		871.25	24.28
LAB- 1	885.	935.	900.	910.		907.50	21.01
LAB- 1	945.	905.	900.	922.		918.00	20.31
LAB- 2	860.	915.	890.	915.	870.	883.00	22.13
	870.	900.	875.	850.	885.		

Table 6a - Analytical Results for BEN-1

Characteristic (mass %)	Laboratory							
	2	3	4	5	6	8	9	11
Structure, -74 µm	89.89	89.00	92.43	90.70	89.20	89.84	92.10	
Structure, +44 µm	5.40	5.50	6.07	4.80	5.92	5.39	26.00*	
Moisture	4.57	5.50	4.50	5.33	3.00*		5.00	4.77
Al_2O_3	17.90	16.60	17.37	15.86		18.52	19.10	18.86
CaO	1.30	2.40*	1.48	1.48		1.49	1.54	1.57
CO_2	1.00			0.968			1.40	0.86
Fe, total	2.74		2.73	1.80*		2.46	2.50	2.59
Fe(II)	0.07			0.30		-		
K_2O	0.628	0.460	0.58	0.625		0.87	0.16*	0.63
Na_2O	2.92	1.35*	2.79	3.19		3.48	2.88	2.89
MgO	2.15	2.10	2.02	1.86		2.21	2.28	2.05
S	0.17		1.86*	0.097		-	0.15	0.17
SiO_2	65.90		62.92	62.58		64.4	60.92	61.71
LOI	6.63	6.40	9.02	9.87		5.36	5.25	4.70

*Outlier

Table 6b - Analytical Results for BEN-2

Characteristic (mass %)	Laboratory							
	2	3	4	5	6	8	9	11
Structure, -74 µm	90.68	90.40	92.67	91.90	91.10	91.40	93.50	
Structure, +44 µm	2.72	2.70	2.96	2.36	3.01	2.56	25.00*	
Moisture	7.34	8.00	7.29	8.00	5.70*		8.00	7.42
Al_2O_3	19.50	18.70	18.83	18.93		20.03	20.28	19.92
CaO	1.08	1.90*	1.21	1.11		1.21	1.28	1.22
CO_2	0.97		0.939				1.36	0.78
Fe, total	3.07		3.03	2.50		2.83	2.87	2.78
Fe(II)	0.45			0.30		-		
K_2O	0.527	0.46	0.53	0.562		0.72	0.12*	0.54
Na_2O	2.15	2.60	2.21	2.27		2.49	2.10	2.23
MgO	2.50	2.30	2.37	2.18		2.50	2.60	2.33
S	0.23		2.23*	0.149		-	0.18	0.17
SiO_2	62.50		61.39	61.34		62.0	56.95	57.99
LOI	7.23	6.80	9.05	10.44		6.59	5.60	4.85

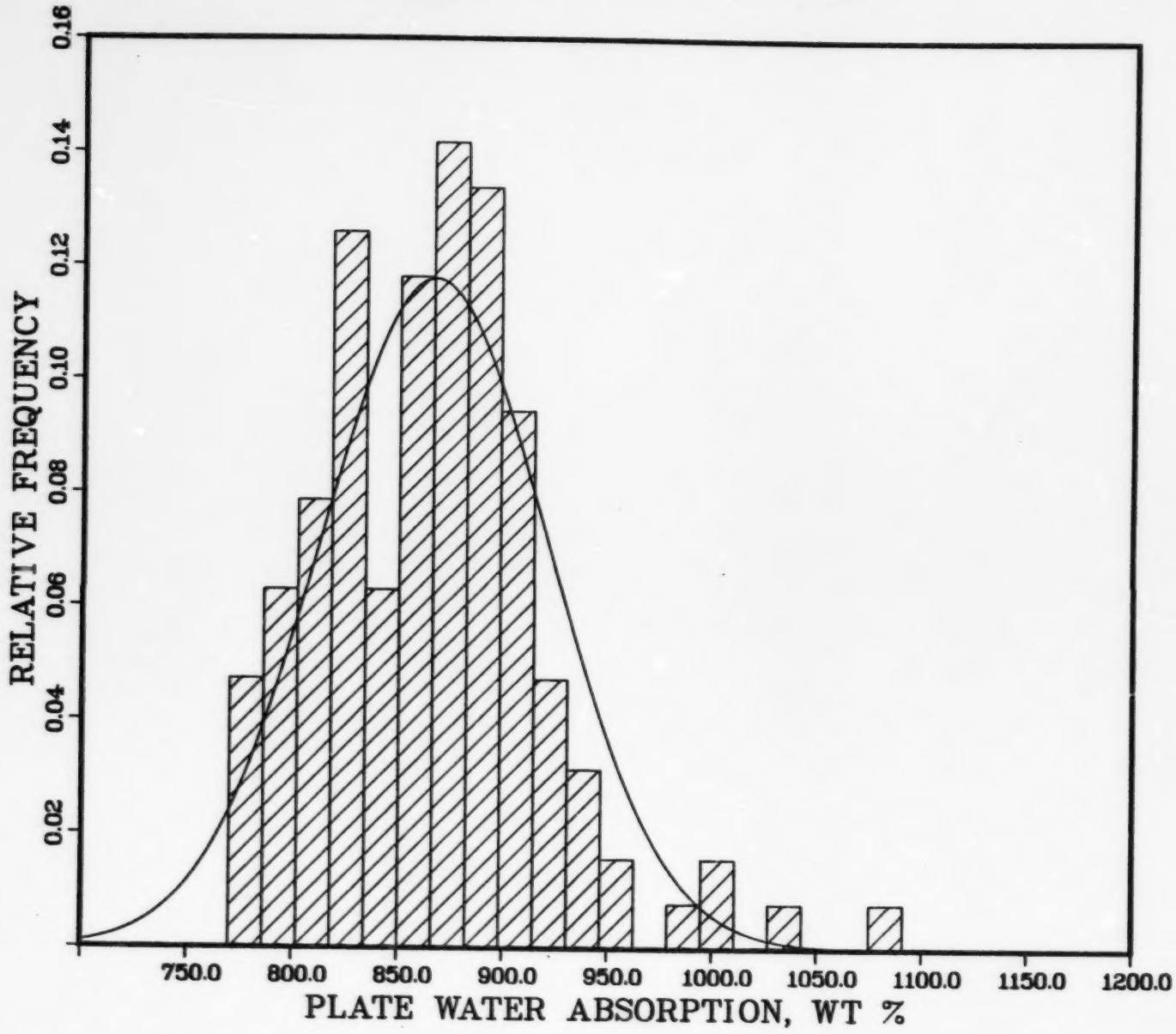
*Outlier

Table 6c - Analytical Results for BEN-3

Characteristic (mass %)	Laboratory							
	2	3	4	5	6	8	9	11
Structure, -74 µm	87.49	86.00	89.54	88.10	86.40	87.20	89.80	
Structure, +44 µm	5.56	6.00	6.04	3.60	6.09	5.44	28.00*	
Moisture	6.95	7.50	6.68	7.40	5.46*		6.50	6.92
Al_2O_3	16.20	15.49	16.50	15.87		17.01	17.11	17.50
CaO	1.03	2.70*	1.86	1.60		1.87	1.75	1.89
CO_2	1.33			1.40			1.72	1.12
Fe, total	3.65		3.16	2.80		3.13	3.08	2.96
Fe(II)	0.45			0.80		-		
K_2O	0.35	0.59	0.43	0.46		0.61	0.11*	0.44
Na_2O	2.39	3.20*	2.49	2.50		2.82	2.52	2.48
MgO	1.12*	1.50	1.51	1.43		1.61	1.73	1.55
S	0.19		1.94*	0.102		-	0.14	0.16
SiO_2	65.65		62.96	63.92		64.5	59.98	60.99
LOI	6.66	6.30	8.90	8.78		5.58	5.10	4.52

*Outlier

REFERENCE MATERIAL BEN–1



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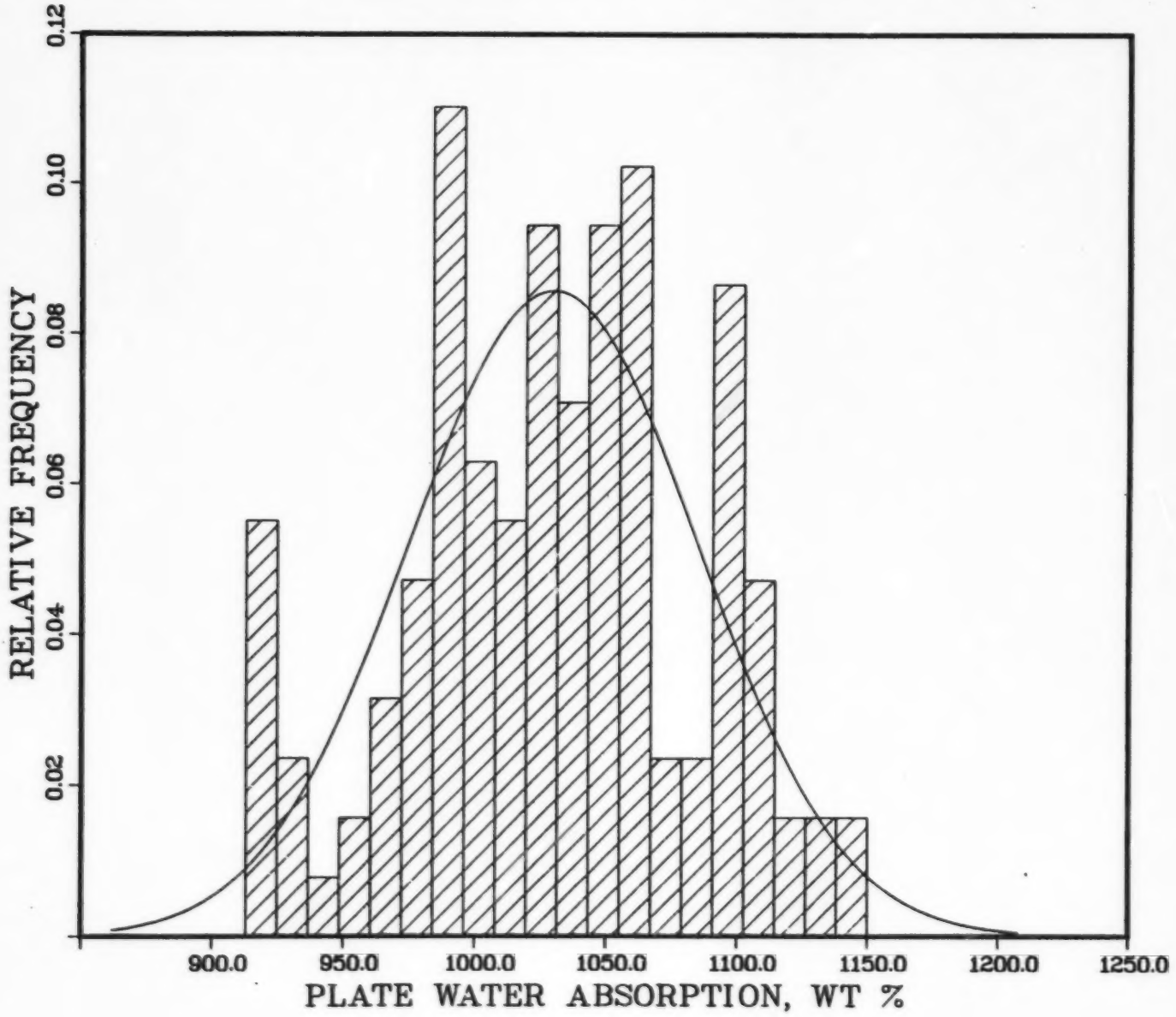

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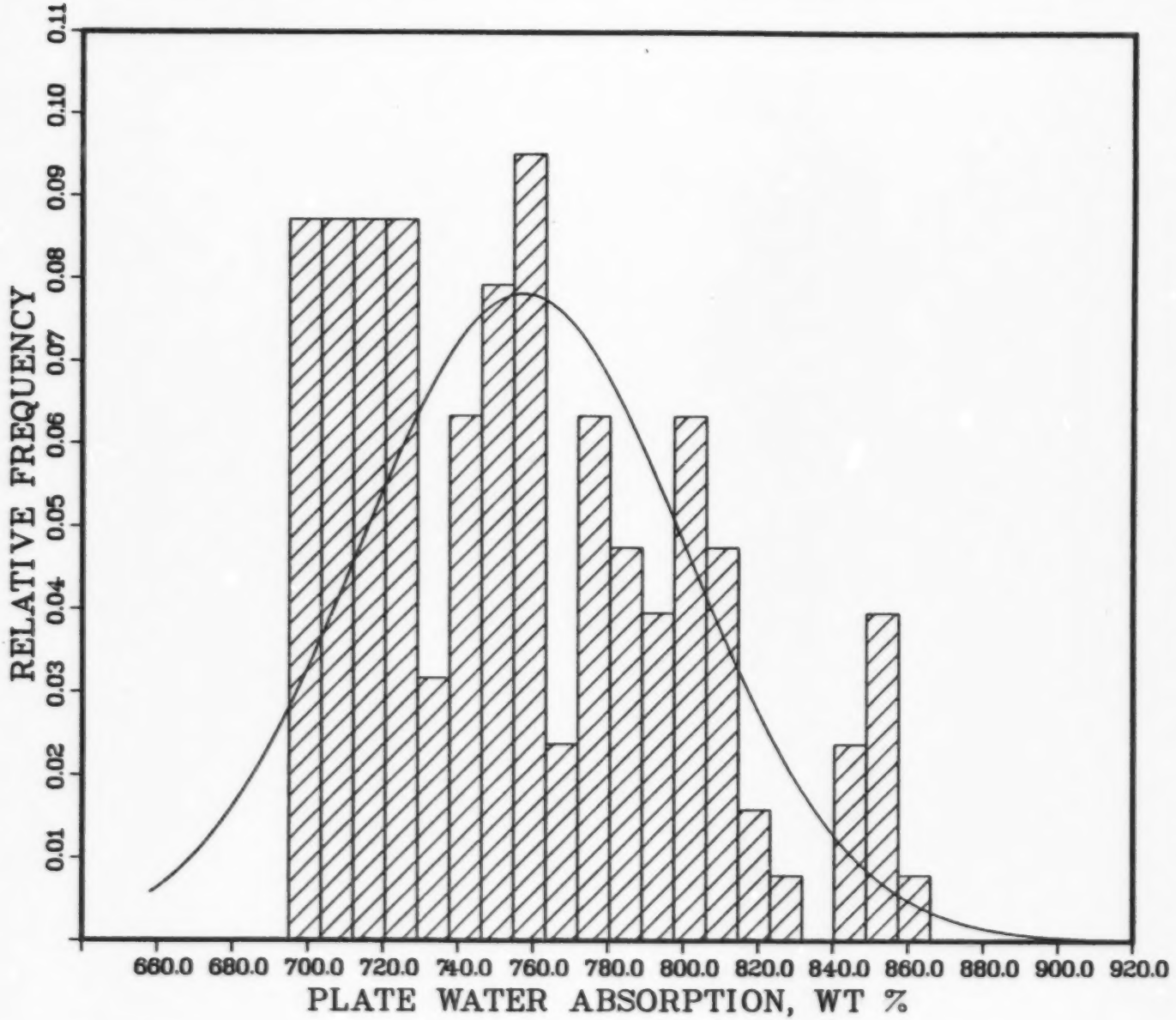

POOR

QUALITY

ORIGINAL